

Review article

# Anatomic anterior cruciate ligament reconstruction using an individualized approach<sup>☆,☆☆</sup>

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## Abstract

Anterior cruciate ligament (ACL) reconstruction is one of the most commonly performed orthopaedic procedures. Recently, there has been a shift in interest towards reconstruction techniques that more closely restore the native anatomy of the ACL. This review paper discusses our approach to individualized anatomic ACL reconstruction, including the anatomy of the ACL, the physical exam, imaging modalities, the surgical technique for anatomic reconstruction including pre- and intraoperative considerations and our postoperative rehabilitation protocol. Copyright © 2014, Asia Pacific Knee, Arthroscopy and Sports Medicine Society. Published by Elsevier (Singapore) Pte Ltd. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

**Keywords:** Anatomic; Anterior cruciate ligament; Individualized; Single-bundle; Double-bundle

## Introduction

Anterior cruciate ligament (ACL) reconstruction is one of the most commonly performed orthopaedic procedures.<sup>1,2</sup> The traditional reconstruction technique for ACL rupture is trans-tibial, arthroscopic single-bundle reconstruction. However, this technique has been shown to achieve good to excellent results in only 60% of patients.<sup>3</sup> In addition, there is a high incidence of osteoarthritis at intermediate- to long-term follow-up.<sup>4</sup>

Recently, there has been a shift in interest towards reconstruction techniques that more closely restore the native anatomy of the ACL.<sup>5</sup> Anatomic ACL reconstruction can be defined as: the functional restoration of the ACL to its native dimensions, collagen orientation, and insertion sites.<sup>6</sup> Complete restoration of the native ACL may not be possible, due to

the complex nature of the ligament. However, since anatomy is the basis of orthopaedic surgery, the surgeon should strive towards close approximation. This paper will discuss the approach to individualized anatomic ACL reconstruction, including the anatomy of the ACL, the physical exam, imaging modalities, the surgical technique for anatomic reconstruction including pre- and intraoperative considerations and the post-operative rehabilitation protocol.

## Anatomy

The ACL consists of two functional bundles, the anteromedial (AM) and the posterolateral (PL) bundles.<sup>7,8</sup> The two bundle anatomy is already present during foetal development<sup>9</sup> and persists throughout life.<sup>10,11</sup> The AM and PL bundle are named after the position of their insertion sites on the tibia. On the femoral side the bundles are vertically aligned, with the AM insertion superior to the PL insertion. However, during surgery, the knee is in a flexed position and the bundles are horizontally aligned with the AM bundle insertion site deeper than the PL bundle insertion site.<sup>12–14</sup>

The tibial insertion site measures on average 11 mm in width and 17 mm in length.<sup>7,12,15–17</sup> The tibial AM bundle insertion site is in line with the anterior horn of the lateral

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meniscus on the tibial plateau. It also has a close relationship with the medial and lateral tibial spine and the tibial insertion site of the posterior cruciate ligament (PCL) (Fig. 1).<sup>6,13,14</sup>

On the femur, the ACL insertion site is shaped like an oval. It is on average smaller than the tibial insertion site, but 3.5 times larger than the ACL mid-substance.<sup>8,18</sup> There are two bony ridges that can be used to identify the femoral ACL insertion site: the lateral intercondylar ridge and the lateral bifurcate ridge.<sup>19–21</sup> The lateral intercondylar ridge is located on the medial wall of the lateral femoral condyle, forming the anterior border of the femoral ACL insertion site, whereas the lateral bifurcate ridge runs perpendicular to the lateral intercondylar ridge and is located between the AM and PL femoral insertion sites (Figs. 1,2).

From a biomechanical perspective, the AM and PL bundle work together to provide both anterior and rotational stability of the knee. The AM bundle is taut throughout the range of motion of the knee, reaching a maximum tension between 45° and 60°, whereas the PL bundle is tight primarily in extension.<sup>19,22–24</sup> The AM bundle is mostly responsible for anteroposterior stability, whereas the PL bundle allows rotation. Together they contribute to characteristic kinematics of the knee.

### Physical examination

The Lachman and anterior drawer tests are the most commonly used tests to assess anteroposterior knee joint laxity, while the pivot shift test can be used to evaluate rotary laxity of the knee. Many factors influence the magnitude of the pivot shift such as the bony morphology, the person performing the test and the status of the menisci.<sup>25</sup> This is why it is important to use the contralateral uninjured knee for comparison, or use other measures to standardize or quantify it.<sup>26–28</sup> A recent meta-analysis of clinical tests for diagnosing ACL rupture found the Lachman test to be the most sensitive for diagnosing an acute, complete ACL rupture.<sup>29</sup> The Lachman, antero drawer and pivot shift tests each had similar specificities.<sup>29</sup> The anterior drawer test may be more useful in cases of a chronic ACL rupture.<sup>30</sup>

If operative management is chosen, the recommendation for repeating the exam under anaesthesia cannot be

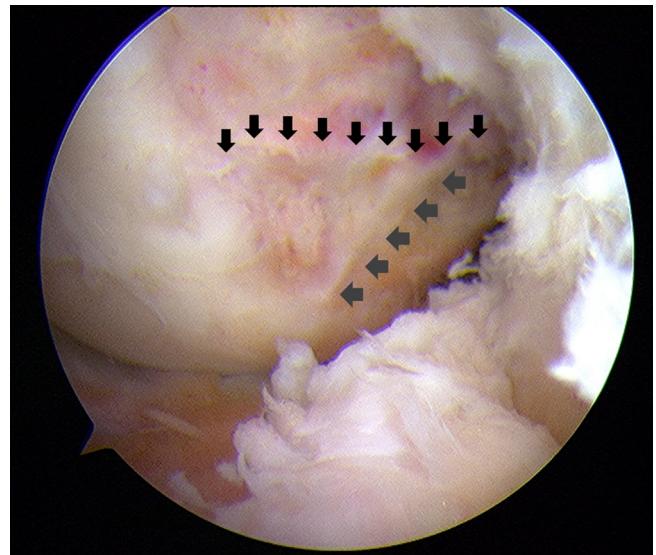


Fig. 2. Arthroscopic picture of a right knee showing the lateral intercondylar ridge (black arrows) and the lateral bifurcate ridge (grey arrows).

underemphasized.<sup>29,30</sup> In these cases, the Lachman remains most sensitive, whereas it is the pivot shift test that has the highest specificity. In addition to these physical diagnostic tests, various commercially available instrumented knee laxity devices may be utilized for objective anteroposterior laxity measurements. In this regard, a recent meta-analysis determined the KT-1000 Arthrometer to have the highest sensitivity, specificity and accuracy for diagnosing ACL rupture.<sup>31</sup>

### Imaging

A standard radiographic knee series, including weight-bearing 45° flexion posterior-anterior (PA) views, 45° flexion lateral views and Merchant views for patellar evaluation should always be obtained to evaluate the bony morphology and potential osseous pathologies. For revision cases, anatomic tunnel location can be evaluated on the weight bearing 45° flexion PA views.<sup>32</sup> A femoral tunnel angle of less than 32.7° is associated with non-anatomic femoral tunnel placement.<sup>32</sup>

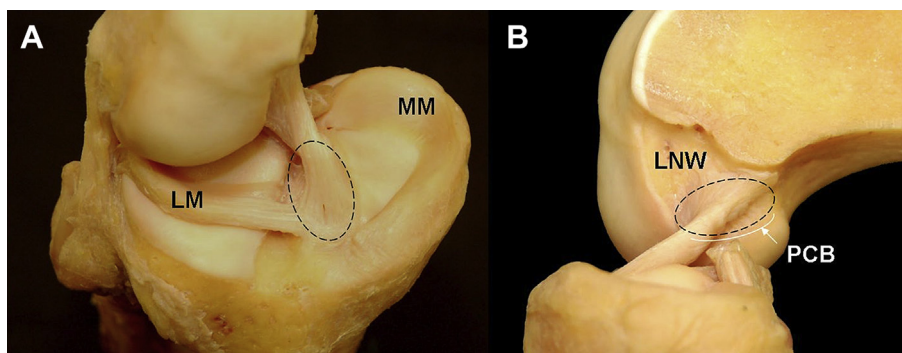


Fig. 1. (A) Cadaveric specimen of a right knee showing the ACL tibial insertion site anatomy (circle) and its relationship between the anterior horn of the lateral meniscus (LM) and the medial meniscus (MM). (B) Femoral insertion site anatomy showing the position on the lateral notch wall (LNW) and posterior cartilage border (PCB).



High-resolution magnetic resonance imaging (MRI) is the gold standard for preoperative evaluation of ligamentous, meniscal and chondral injuries.<sup>33–35</sup> Although the ACL can be visualized with T1- or T2-weighted images on “standard” views in the coronal and sagittal planes, a clear discrimination between the anteromedial and posterolateral bundles may be difficult. Therefore, obtaining special MRI in the oblique coronal and oblique sagittal planes may enhance visualization.<sup>36,37</sup> These views are acquired by cutting MRI sections in the same anatomic alignment as the ACL, which allows for a clear and predictable recognition of partial ACL tears.<sup>38</sup>

Additionally, findings and special measurements from these MR images can be used to help guide preoperative planning with regard to the most appropriate surgical technique and graft choice. Some measurements of the native ACL that can be performed on MRI include: the tibial insertion site length (normal range 9–25 mm), ACL inclination angle (normal range 43°–57°), ACL length (normal range 25–45 mm), and thickness of the quadriceps- and patellar tendons (if these are planned to be used as an autograft).<sup>32</sup>

### Surgical technique

There is a role for non-operative treatment for ACL injuries.<sup>39</sup> However, this extends beyond the scope of this paper. When the surgeon decides to treat the ACL injury surgically, there are several considerations. Preoperative range of motion, swelling and quadriceps strength have been shown to affect the ultimate success of ACL reconstruction.<sup>40,41</sup> Persistent preoperative swelling and limited range of motion are significantly correlated with decreased range of motion and the development of arthrofibrosis after surgery.<sup>40</sup> In addition, preoperative quadriceps strength deficits of greater than 20% significantly affect the long-term functional outcome of ACL reconstruction.<sup>41</sup> Therefore, physical therapy prior to undergoing surgery should focus on regaining range of motion, reducing swelling and strengthening the surrounding musculature of the knee.

Operative treatment of the ACL should focus on restoring both the native insertion site anatomy and tensioning pattern of the ACL, as well as individualizing the procedure to each patient. The definition of anatomic ACL reconstruction is the functional restoration of the ACL to its native dimensions, collagen orientation and insertion sites.<sup>6</sup>

Intraoperatively, the rupture pattern of the ACL should be confirmed, and, if a partial one-bundle rupture is evident, augmentation surgery should be considered (Fig. 3).<sup>42,43</sup> Careful dissection and preservation of the native insertion sites can facilitate the determination of appropriate tunnel locations. The femoral and tibial insertion sites can best be visualized using a three-portal approach.<sup>44</sup> This approach has the standard anterolateral and central medial portal, and in addition an accessory anteromedial portal (Fig. 4). This last portal is located superior to the medial joint line approximately 2 cm medial to the medial border of the patellar tendon. Using all three portals as viewing and instrumentation

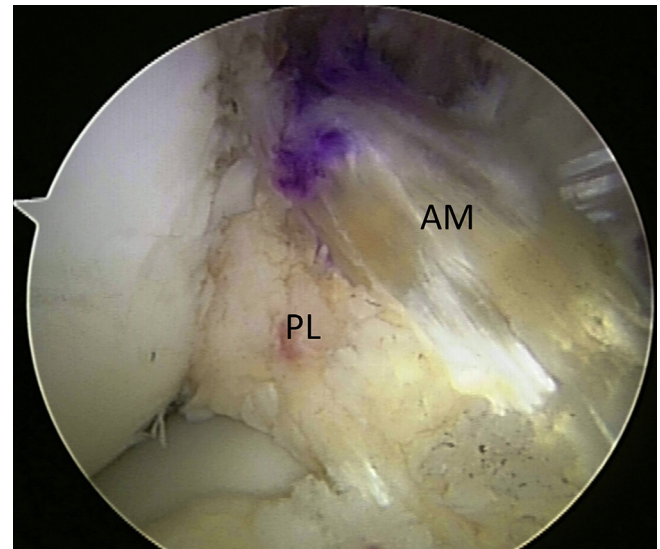


Fig. 3. Arthroscopic view of a right knee after augmentation surgery. PL = native PL bundle; AM = AM graft after AM bundle augmentation.

portal interchangeable, will allow viewing of the entire ACL, including its insertion sites.

The decision to perform anatomic single-bundle or double-bundle ACL reconstruction is based on several criteria.<sup>6</sup> One

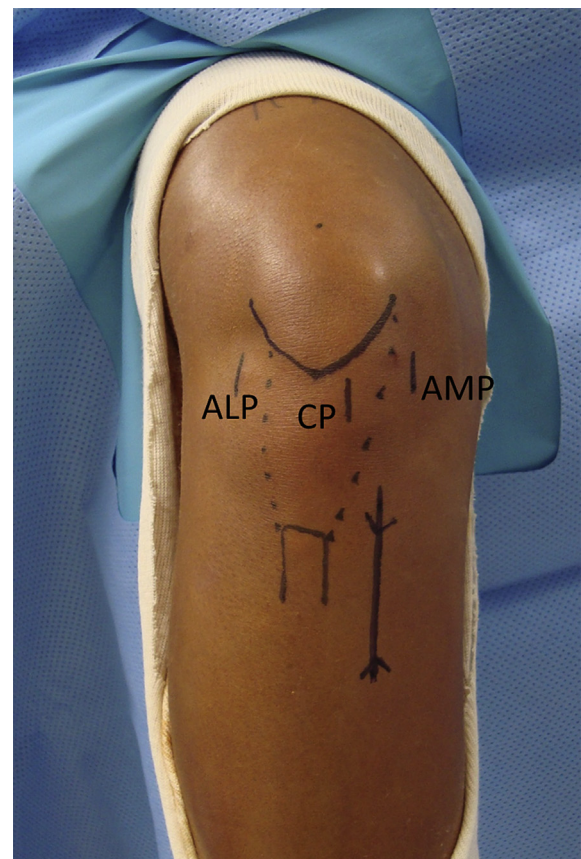


Fig. 4. Outside appearance of a right knee showing the portal placement. ALP = anterolateral portal; CP = central portal; AMP = accessory anteromedial portal.

of the considerations is the size of the patient's native ACL insertion site. Typically, a tibial insertion site size of less than 14 mm measured arthroscopically is too small to accommodate a double bundle reconstruction.<sup>18</sup> Arthritic changes, multiligament injury, severe bone bruising, open physes and a narrow notch width are considered indications to perform single-bundle reconstruction.<sup>37</sup> Variation in the shape of the notch can also influence the decision for single- or double-bundle.<sup>45</sup> Attempting to drill two femoral tunnels in the setting of a narrow notch can cause damage of the articular cartilage of the medial femoral condyle. It is important to measure both the insertion site size and the notch width with an arthroscopic ruler as there has been shown to be only a weak correlation between the two.<sup>46</sup>

Graft choice is another important consideration in ACL surgery. Potential graft types include bone-patellar-tendon-bone autograft, hamstring tendon autograft, quadriceps tendon autograft, and allograft (Fig. 5). For the purposes of preoperative planning, bone-patellar-tendon-bone and quadriceps tendon autografts can be measured preoperatively on sagittal MRI. Studies have also evaluated the use of MRI in predicting hamstring graft size and determined it was not very

reliable or accurate.<sup>47</sup> While allograft eliminates donor site morbidity, a recent prospective analysis of predictors of failure revealed that in a younger patient age and early return to sports in both single- and double-bundle reconstructions to be associated with a higher rate of failure.<sup>48</sup> Ultimately, daily activities and lifestyle of the patient should dictate an individualized graft choice.<sup>49</sup>

Proper tunnel placement is critical in anatomic ACL reconstruction. Non-anatomic tunnel placement has long been shown to decrease range of motion and increase graft tension, cause impingement and lead to graft failure.<sup>50</sup> Several intraoperative and postoperative methods have been described to evaluate tunnel placement, including intraoperative guide wire assessment via fluoroscopy,<sup>51</sup> postoperative radiographic evaluations,<sup>32</sup> comparing the pre- and postoperative MRI measurements of insertion site, inclination angle and length of the ACL,<sup>32</sup> and three-dimensional (3D) computed tomography (CT) scan is.<sup>52</sup> The latter is presently considered the gold standard by which tunnel placement can be critically evaluated. Moreover, having a 3D-CT scan can be particularly useful in planning ACL revision surgery.<sup>52–54</sup>

### Double-bundle reconstruction

In anatomic double-bundle reconstruction, the AM and PL tunnels are placed in the centre of the native AM and PL tibial and femoral insertion site (Fig. 6). The size of the tunnels is determined by the size of native ACL insertion site, aiming to restore as much of the insertion site as possible. When the PL footprint is smaller than the AM, this should be respected and a 2-mm bony bridge should always be present between the two bundles. So for example, when the insertion site length is 16 mm, the AM bundle width is 8 mm and the PL bundle width is 6 mm, with a bony bridge of 2 mm, the tunnels can be 6 mm for the PL and 8 mm for the AM. The graft size should be equal to the tunnel diameter. The femoral PL tunnel is created first, through the accessory anteromedial portal, followed by the tibial AM and PL tunnels. Then the femoral AM tunnel is drilled, either through the accessory medial portal or through the tibial AM or PL tunnel if this allows for the native femoral insertion site to be reached.<sup>6</sup> After the tunnels have been drilled, the grafts are prepared. The AM and PL grafts are tensioned separately, with the AM in approximately 45° of flexion and the PL graft in full extension. Interference of suspensory fixation can be used to fixate the graft away from the insertion site, not to disturb the native insertion site anatomy.

### Single-bundle reconstruction

For anatomic single-bundle reconstruction, the femoral and tibial tunnels are placed in the center of the measured femoral and tibial ACL insertion site (Fig. 7). The femoral and tibial tunnel location should be matched.<sup>55</sup> Similar to double-bundle reconstruction, the size of the tunnel is determined by the size of the ACL footprint. The graft size should be equal to the tunnel size. An oval dilator can be used to better replicate the

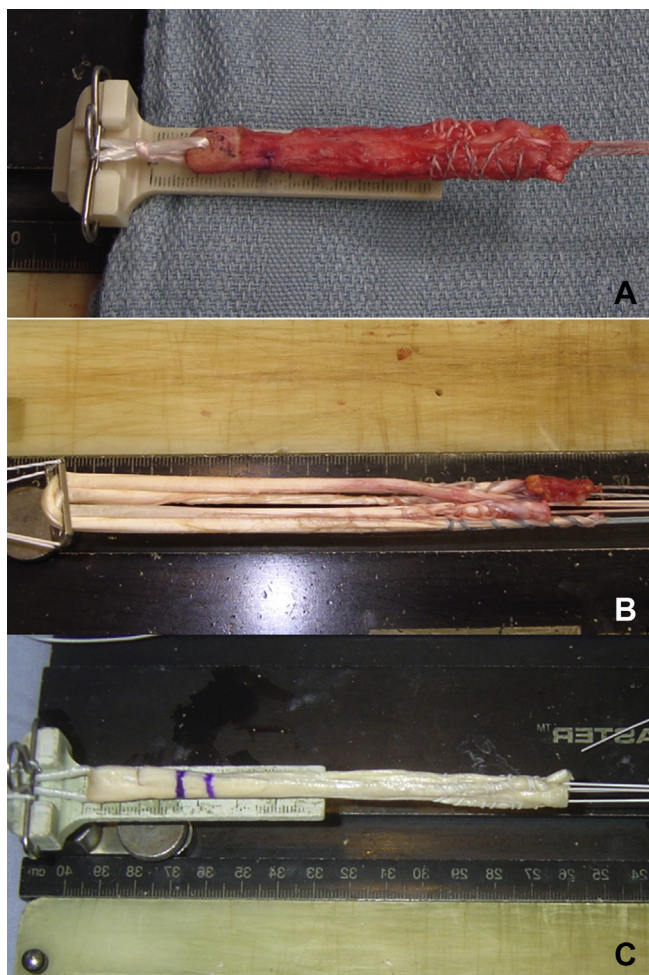


Fig. 5. Different graft types in ACL reconstruction. (A) Quadriceps autograft. (B) Hamstring autograft. (C) Anterior tibial allograft.



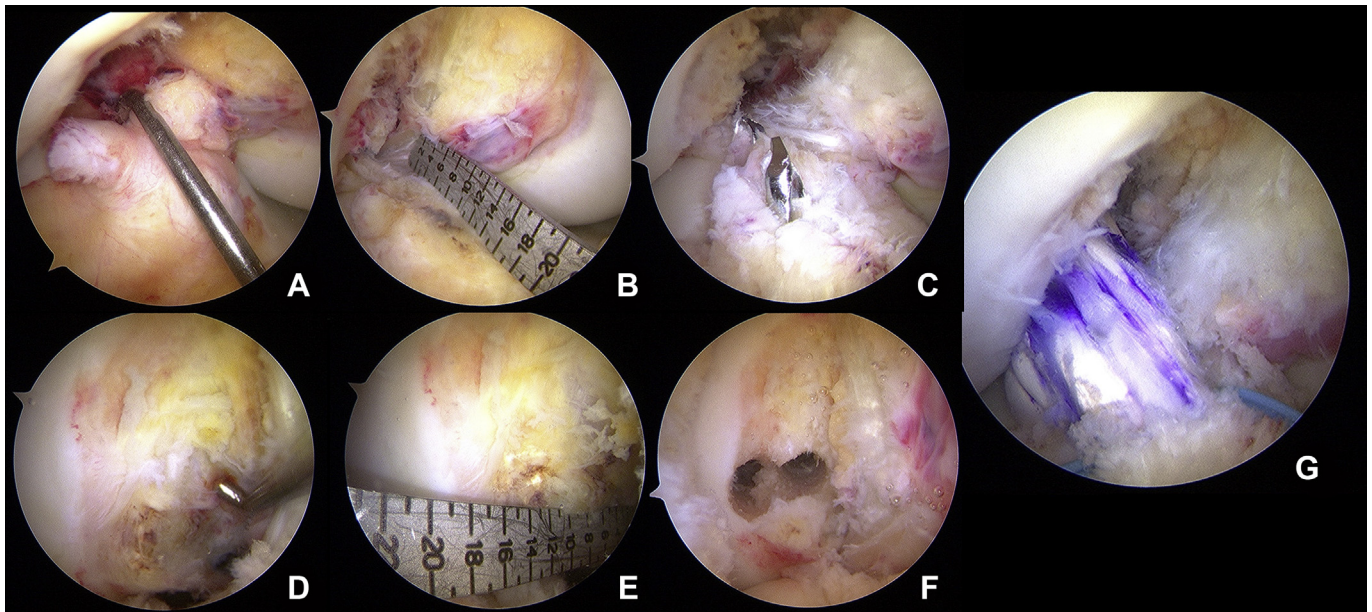


Fig. 6. Arthroscopic pictures of the right knee of an anatomic double-bundle reconstruction. (A) Inspecting the rupture pattern of the native ACL with both bundles torn. (B) Measuring the tibial insertion site. (C) The tibial tunnels are placed in the AM and PL insertion site. (D) Femoral insertion site with the lateral intercondylar ridge visible. (E) Measuring the femoral insertion site. (F) The femoral tunnels are placed in the AM and PL insertion site. (G) End results after anatomic double-bundle ACL reconstruction.

shape of the native ACL insertion site. The graft is fixed close to extension in order not to over constrain the functional PL component of the single-bundle graft.<sup>56</sup>

### Rehabilitation

The main focus of the early postoperative period is achieving full range of motion in the operated knee, which has been recognized to improve overall outcome.<sup>50,57</sup> Range of motion should be measured relative to the non-involved knee; a side to side difference of greater than  $3^\circ$  for extension has been associated with persistent pain and the development of early osteoarthritis.<sup>58</sup> Accelerated rehabilitation protocols have become popular recently, meeting the wishes of young

athletes in their desire to return to their sport.<sup>59</sup> However, this group is poorly compliant and faster return to activity may increase the re-injury rate.

In the first 6–8 weeks after surgery, the focus is on restoring range of motion and improving quadriceps strength. Weight-bearing activities are also increased slowly to full weight bearing emphasizing use of a normal gait.

Three to 6 months after surgery, joint motion should fully return, allowing the patient to be involved in normal daily activities as well as some low impact but linear sports such as jogging and cycling. The strengthening exercises are continued, both in weight-bearing and non-weight-bearing format. The quadriceps and hamstring muscles need to be strengthened to prevent valgus collapse of the knee, which is

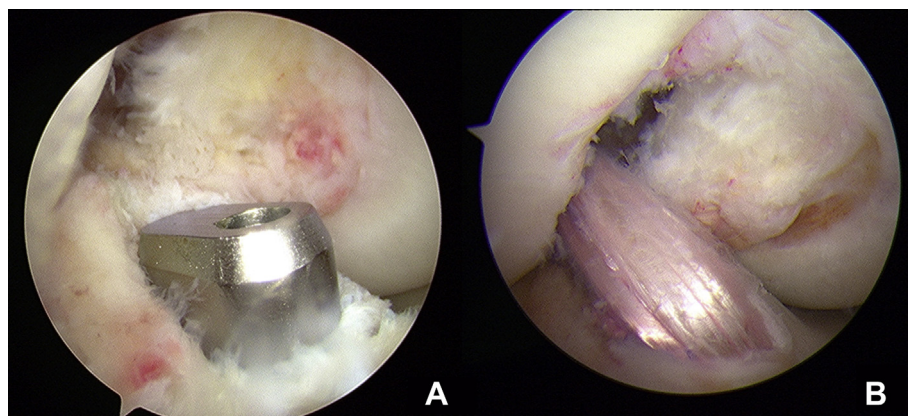


Fig. 7. Arthroscopic pictures of the right knee of an anatomic single-bundle reconstruction. (A) An oval dilator can be used to better mimic the shape of the native ACL insertion site. (B) End results after anatomic single-bundle ACL reconstruction.

associated with the mechanism of ACL injury. Core muscles need to be trained for balance and neuromuscular control of the body.

In the last phase of rehabilitation, between 9 and 12 months postoperatively, muscle strength has returned to preoperative levels and graft healing is thought to have neared completion. Exercise intensity should increase gradually to the pre-injury activity level, including cutting exercises. Functional bracing may be used during the return to competitive sports.

Biomechanical studies have shown that graft forces are higher when the graft is positioned anatomically.<sup>60</sup> Thus, progression after anatomic ACL reconstruction should be somewhat slower than rehabilitation protocols after conventional non-anatomic single-bundle reconstruction. It should also be slower when allograft tissue is used.

## Conclusion

The ACL consists of two functional bundles, the anteromedial (AM) and the posterolateral (PL) bundles. Anatomic ACL reconstruction aims to restore the ACL to its native dimensions, collagen orientation and insertion site. There are several pre-, intra- and postoperative considerations for single- versus double-bundle reconstruction. The surgery should be individualized to each specific patient to provide the patient with the best potential for successful outcome.

## Conflicts of interest

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